POSSIBILITY OF SIMULTANEOUS ACCELERATION OF H^- AND D^- WITH A CYCLOTRON

N.Nakanishi
Riken
Wako-shi, Saitama-ken, 351-01 Japan

Abstract

The energy up to which H^- and D^- beams can be accelerated simultaneously with a cyclotron is described based on numerical calculation. The achievable energies for H^- and D^- beams are 14 and 7 MeV, respectively. Thus it will be possible to employ the technique in a compact cyclotron for medical use.

Introduction

Compact cyclotrons have been used extensively in isotope production, micro-analysis, non-destructive test and so on.Specially they play an important role in producing such positron emitters as ^{11}C, ^{13}N, ^{15}O and ^{18}F for positron emission tomography which is one of promising imaging techniques for in-vivo studies. They are almost positive ion cyclotrons. Recently, however, negative ion cyclotrons are coming in fashion because of some merits in view of beam extraction, energy variability, and beam intensity.

On the other hand, PET is applied to diagnostics of canser in internal organs or studies on brain function. The former has been in great demand increasingly, and recently the plural PET device has a tendency to be installed in hospitals. Really, negative ion cyclotrons with multiple extraction channels have been developed vigorously.[1、2] From such circumstances in the nuclear medicine field, simultaneous acceleration of H^- and D^- beams with a cyclotron was proposed as a new trial.

An accelerated beam in a negative ion cyclotron is extracted by using a thin stripping foil of corbon or aluminum. The fact makes 100% extraction efficiency possible and moreover, makes variability of extraction energy of beams easy. These are the most marked features which positive ion cyclotrons do not possess. The simultaneous acceleration of H^- and D^- beams is possible by installing two internal ion sources at two opposite dees, and by extracting p and d toward opposite directions with two stripping foils at a nearly equal radial position. Interest focuses on the final energies of these particle beams. Whether is the achievable energy meaningful in practical use or not ? Here, a preliminary result on the energy is given based on numerical calculation.

Calculation

Two computer programs were used. One makes the magnetic field with different radial distributions in a cyclotron, and the other traces a particle orbit and related quantities in the magnetic field and

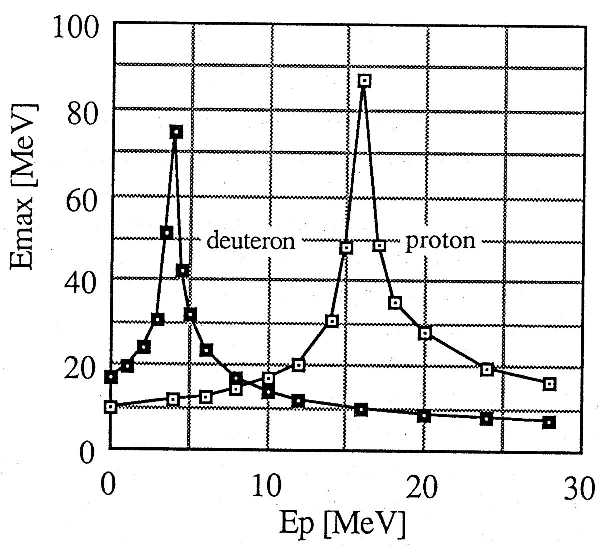

Fig.1 Maximum energies of H^- and D^- particles vs. Ep. See the text for the meaning of Ep. Dee angle is 45° .

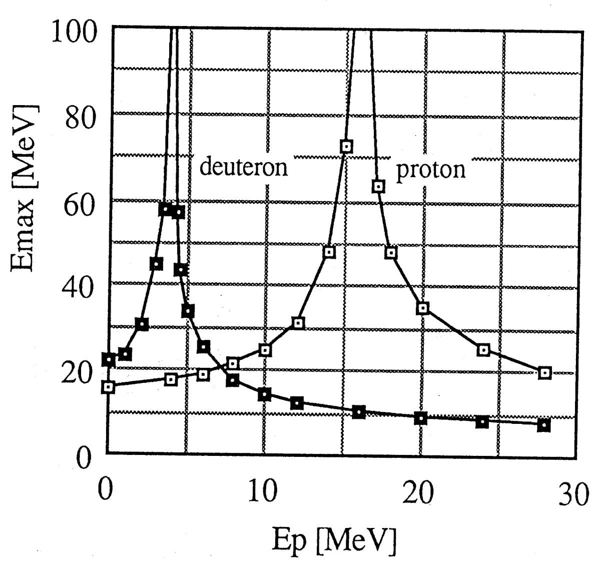

Fig.2 Maximum energies of H^- and D^- particles vs. Ep. See the text for the meaning of Ep. Dee angle is 90° .

in a two-dee system. H^- and D^- particles which have different relative distance and direction between each ion source and puller, and different initial rf phases, are traced in a common magnetic field, radio-frequency and accelerating voltage, until they phase out the accelerating region in radio frequency to reach at their final energies.

The starting condition at ion sources of the particles was set so as to realize centered orbits.

It will be considered that the maximum energies of the two particles depend on not only the radial shape of the magnetic field strength and radio-frequency but also the rf voltage and harmonic numbers related to dee angle. It is easily found out that the higher the accelerating voltage is, the higher the maximum energy is. The voltage, however, is desirable to be as low as possible in view of reduction of the electrical power consumption and avoidance of the discharge phenomenon. Here, the voltage is taken to be 60 kV tentatively. The central magnetic field strength after a bump field deduction is set to be 1.2 T so that the first turn of each accelerated particle is not interfered with both of the partner and its own ion sources. We can make various radial distributions of magnetic field. As one of examples, an adopted system is the isochronous field for H^- beams to be accelerated to Ep at the radius of 48 cm. Therefore, the relative radial distribution is specified by the H^- energy Ep which the particle achieves at the radius of 48 cm. Incidently, results of calculation do not depend on these parameters. These influence accuracy of formation of magnetic field and radio-frequency. Figures 1 and 2 show the achievable maximum energy in the case of 45° and 90° dees, respectively, where the abscissa Ep means, as mentioned above, the energy to which H^- particles get at the radius of 48 cm. Harmonic numbers of H^- and D^- are 2 and 4, and 1 and 2 in the dee angles of 45° and 90°, respectively. Points in figures mean calculated values. Evidently, the maximum energy in the case of a 90° dee exceeds one in the case of a 45° dee. The figures also show three different regions of Ep<4 MeV, 4 MeV<Ep<16 MeV and 16 MeV<Ep which are favorable for D^-, both and H^-, respectively. It seems that an objective magnetic field distribution exists in the region of 6 MeV<Ep<12 MeV. Frequency dependence of the maximum energy of both particles are shown in Figs 3-5 together with half of the H^- energy and twice of the D^- energy for typical distributions of Ep= 0, 8 and 20 MeV, respectively. The energies corresponding to the crossing points of both the curves of the H^- energy Ep and twice of the D^- energy 2Ed, and that of the D^- energy Ed and half of the H^- energy 2Ep are the achievable maximum energies of H^- and D^- particles, respectively.

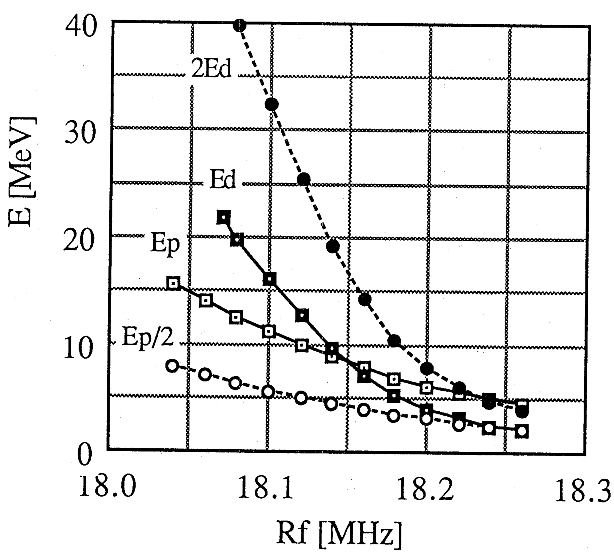

Fig.3 Radio-frequency dependence of maximum energies at the magnetic field Ep=0MeV. Ep, Ed, Ep/2, and 2Ed in the figure mean maximum energies of H^- and D^-, half of H^- energy and twice of D^- energy, respectively.

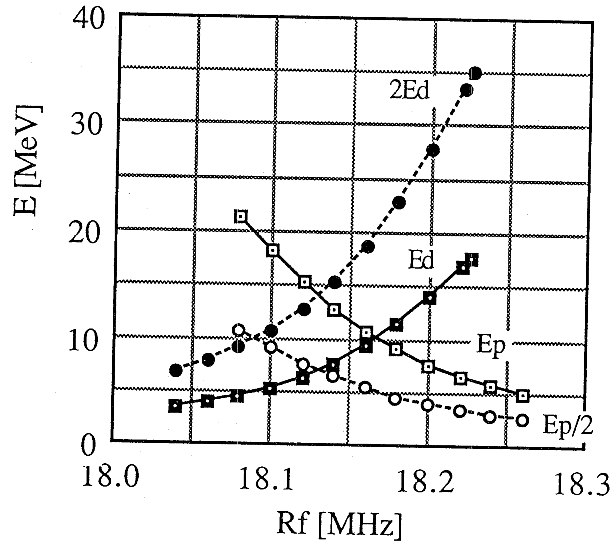

Fig.4 Radio-frequency dependence of maximum energies at the magnetic field Ep=8MeV. See also the caption of Fig.3

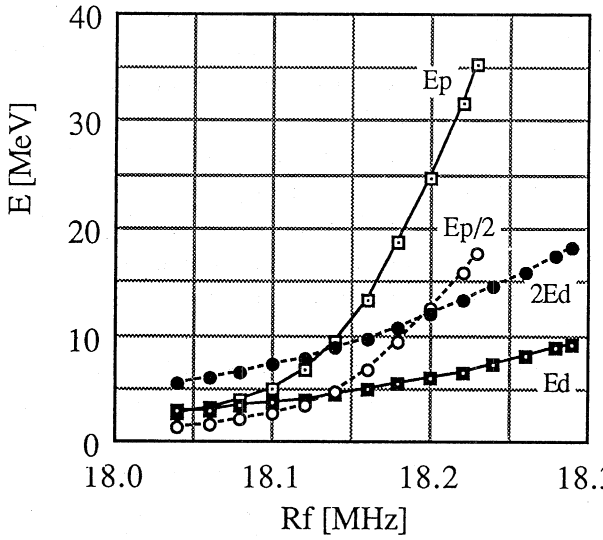

Fig.5 Radio-frequency dependence of maximum energies at the magnetic field Ep=20MeV. See also the caption of Fig.3

Discussion and Conclusion

From Fig.4, the maximum energies of H^- and D^- particles are found to be 14 and 7 MeV, respectively. In the region of 6 MeV<Ep<12 MeV, the values are almost constant in spite of different radio-frequency dependence of the maximum energies for both the particles. In Figs.1-5, gradient of curves is related to the standard of accuracy or stability of magnetic field or radio-frequency. Parameters must be chosen from the parameter space where the gradient of curves is not steep.

It is expected that such a cyclotron with energy constant K=14 MeV will be useful for isotope production. Producible positron emitters for PET are summarized in Table 1. It is said that the proton energy of around 17 MeV and the deuteron one of around 10 MeV are suitable for these reactions in view of yield of isotopes and contamination by other reactions. Even if the energies in the case of simultaneous acceleration are less than these values, the cyclotron will do as well, since incident energy dependence of yield is not so large.

Hereafter, condition for simultaneous extraction must be investivated.

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Table 1

Positron emitters for PET

Isotope	Half Life(min)	Nuclear Reaction	Q-Value(MeV)
^{11}C	20.4	$^{14}N(p,\alpha)^{11}C$	-2.92
^{13}N	9.97	$^{16}O(p,\alpha)^{13}N$	-5.22
		$^{13}C(p,n)^{13}N$	-3.00
		$^{12}C(d,n)^{13}N$	-0.28
^{15}O	2.04	$^{14}N(d,n)^{15}O$	5.07
^{18}Fe	109.8	$^{20}Ne(d,\alpha)^{18}Fe$	2.80
		$^{18}O(p,n)^{18}Fe$	-2.44

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2. B.F.Milton, G.Dutto, R.Helmer et al, Proc. 2nd European Particle Accelerator Conf., Nice,1990, p1812